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EVALUATION OF A HIGH FREQUENCY MICROSEISMIC ROCK FAILURE WARNING SYSTEM IN HARDROCK MINES

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by

P. MacDonald*

ABSTRACT

Tests were conducted at three hardrock mines in Northern Ontario to evaluate the 'Stress Alert', a commercial instrument that was originally developed to give warning of roof falls in coal mines. Sensitivity to mining operations, such as drilling, blasting and crushing was investigated. Monitoring was also conducted in zones of excavation, instability and rock failure.

It was found that the effects of blasting could be detected up to an average distance of 15 m. Since no major roof falls or rock failures occurred in the vicinity of the test sites, the ability of the instrument to provide a warning of these occurrences could not be determined. However, results suggested a maximum range of sensitivity of 25 m from the point of fracture. Unreliable chart recorders reduced the value of some test results, and the overall effects of variations in transducer mounting and threshold settings could not be assessed.

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EVALUATION D'UN SYSTEME D'AVERTISSEMENT DE LA RUPTURE DES ROCHES PAR SIGNAUX MICROSISMIQUES DE HAUTE FREQUENCE

par

P. MacDonald*

RESUME

Dans trois mines en roche dure du nord de l'Ontario, on a effectué des essais pour évaluer "le système d'avertissement de contraintes", un instrument commercialisé qui initialement servait à avertir des éboulements du toit dans les mines de houille. On a étudié la sensibilité aux travaux miniers, tels que forage, sautage et broyage. On a aussi serveillé le terrain dans les zones d'excavation, d'instabilité et de rupture de la roche.

On a constaté que l'on pouvait déceler les effets des tirs de mine jusqu'à une distance moyenne de 15 m. Puisqu'à proximité des sites d'expériences, il ne s'est produit aucun éboulement important du toit et aucune rupture sérieuse de la roche, on n'a pu déterminer la capacité de l'instrument à nous prevenir de ces accidents. Toutefois, les résultats ont suggéré l'existence d'un rayon maximal de sensibilité, égal à 25 m à partir du point d'origine de la fracture. Des enregistreurs graphiques peu faibles ont amenuisé la valeur de certains résultats expérimentaux, et l'on n'a pu évaluer les résultats globaux des variations dans le montage des transducteurs et l'établissement des seuils.

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CONTENTS

	Page
ABSTRACT	i
RESUME	ii
INTRODUCTION	1
THE STRESS ALERT	1
TEST SITES	2
Creighton Mine	4
New Quirke Mine	6
MacLeod Mine	6
RESULTS	7
Creighton Mine	7
Summary	10
New Quirke Mine	12
Summary	15
MacLeod Mine	15
Summary	19
CONCLUSIONS	19
REFERENCES	21
ACKNOWLEDGEMENTS	21

FIGURES

No.		
1.	Stress Alert rock stress monitor:	
	a) Stress Alert	3
	b) Two channel chart recorder	3
2.	Example chart record	5
3.	Monitoring sites, Creighton Mine, 6400 level	9
4.	Monitoring sites, Creighton Mine, 7000 level	11
5.	Monitoring sites, New Quirke Mine	13
6.	Monitoring sites, MacLeod Mine	16
7.	Monitoring sites, MacLeod Mine, 3361 block	18

INTRODUCTION

Research and development of a microseismic roof fall warning system was conducted by Integrated Sciences Inc., of Colorado, under a grant from the U.S. Bureau of Mines (1,2). The investigations resulted in a commercial instrument, sold under the name 'Stress Alert' by McPhar Mine Systems Inc., Toronto. Results of preliminary tests in western U.S.A. coal mines (1,2) suggested that a warning of an impending roof fall could be derived by monitoring high frequency acoustic emission, the character of which changed prior to actual failure.

After the results from American coal mines, and some encouraging tests in Canadian Potash mines (3), it was decided to evaluate the potential of the system for warning of rock failure in hardrock mines. A series of tests was therefore arranged to fulfil the following objectives.

1. To investigate the sensitivity of the instrument to vibrations from mining machinery;
2. To determine the general range of detection, suggested as up to 150 m in coal mines;
3. To measure the 'background' levels of microseismic activity detected by the 'Stress Alert';
4. To discover if the instrument is capable of detecting stress changes associated with different types of excavation instability, e.g., roof falls, rock bursts;
5. Should a failure be monitored, then to observe patterns of activity prior to the event.

THE STRESS ALERT

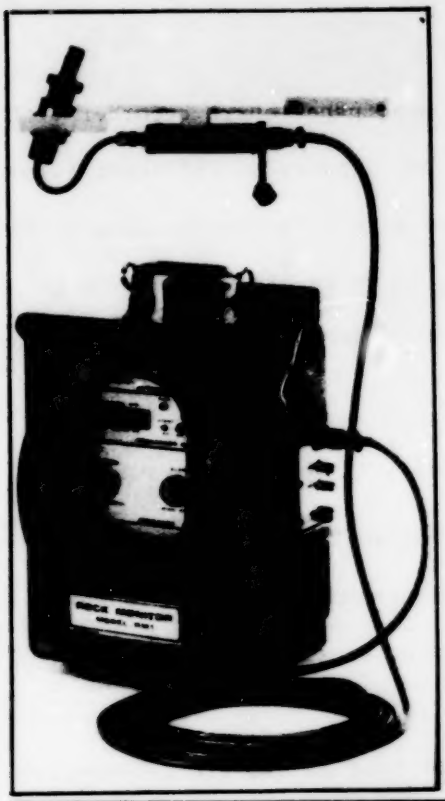
As used in the tests described below, the instrument comprised:

(i) the transducer, attached by cable to (ii) the processing and display module, and (iii) a two-channel strip chart recorder module. The detector and processing unit are presented in Fig. 1(a) and the recorder is shown in Fig. 1(b).

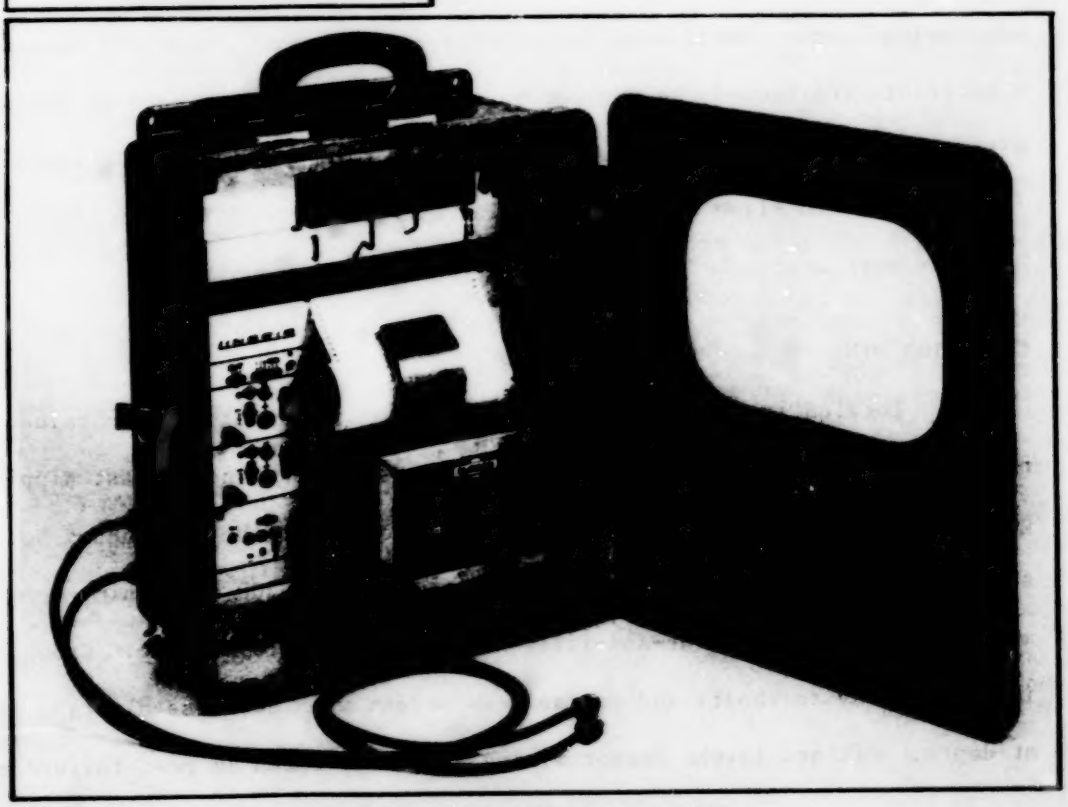
i) The detecting element is a piezo-electric crystal which generates an electrical charge in response to the force applied to it. This force originates from the vibration in the rock onto which the crystal is attached. A preamplifier provides signal amplification and conditioning, for transmission to the processing unit. Transducer response is flat over the range 40-100 kHz.

A plastic bracket is included enabling the transducer to be clamped to the head of a rockbolt. The force of a spring then presses the crystal face against the rock surface.

ii) A variable threshold in the processing unit causes the unit to be triggered, and a light emitting diode to be activated, each time the rectified signal exceeds the threshold value. Two parameters are then calculated each 60 second interval, and one can be observed on the liquid crystal display. First, the number of times the threshold is exceeded is counted, and termed the event rate. In addition, a 300 kHz clock is used to determine an expression for the total energy during the interval. In each small time period during which the signal is greater than the threshold, the number of oscillator pulses are counted. This 'energy count' is then divided by the number of individual events to derive the 'stress factor'. The event rate and stress factor are output continuously and updated at the end of each 60 second interval. Maximum output values are preset at 20,000 events/minute and 2,000 respectively, with an audible and visual alarm indication activated at a stress factor of 1,000.



(a) Stress Alert.



(b) Two channel chart recorder.

Fig. 1 - Stress Alert rock stress monitor.

iii) The recorder module contains a two pen, paper chart recorder with variable amplitude and speed settings. Traces of different colours are used to represent the event rate and stress factor for continuous periods up to 3 days. An example record is shown in Fig. 2, however the charts, being coloured, do not reproduce well, therefore individual records are not included in this report.

TEST SITES

Installation of the Stress Alert in working areas with stable mine openings provided two results. First, 'background' levels of acoustic emission and additionally, an indication of instrument sensitivity to vibrations from machinery propagated through both air and rock.

Bearing in mind the infrequency of roof falls, etc., long-term monitoring studies would have been preferable. However, time and manpower constraints restricted the project to a two-week period at each of three mines, with three different ore types, host rock and mining methods. Creighton Mine (INCO Ltd.), Rio Algom's New Quirke Mine and the MacLeod Mine of Algoma Ore Division were approached and consented to the test proposals.

CREIGHTON MINE

Located in the Sudbury basin, the ore at Creighton is contained principally in norite host rocks, with minor stringers and sheets, dipping generally at 60° NW. Initial extraction was open-pit, but Creighton No. 9 shaft now accesses ore down to depths in excess of 2,300 m. Mining methods are cut-and-fill, undercut-and-fill and large blasthole stoping. Ground control is achieved by rockbolts and coarse mesh screen with destress blasting practised at depth. Pillars in the deeper mining areas are often in post-failure mode.

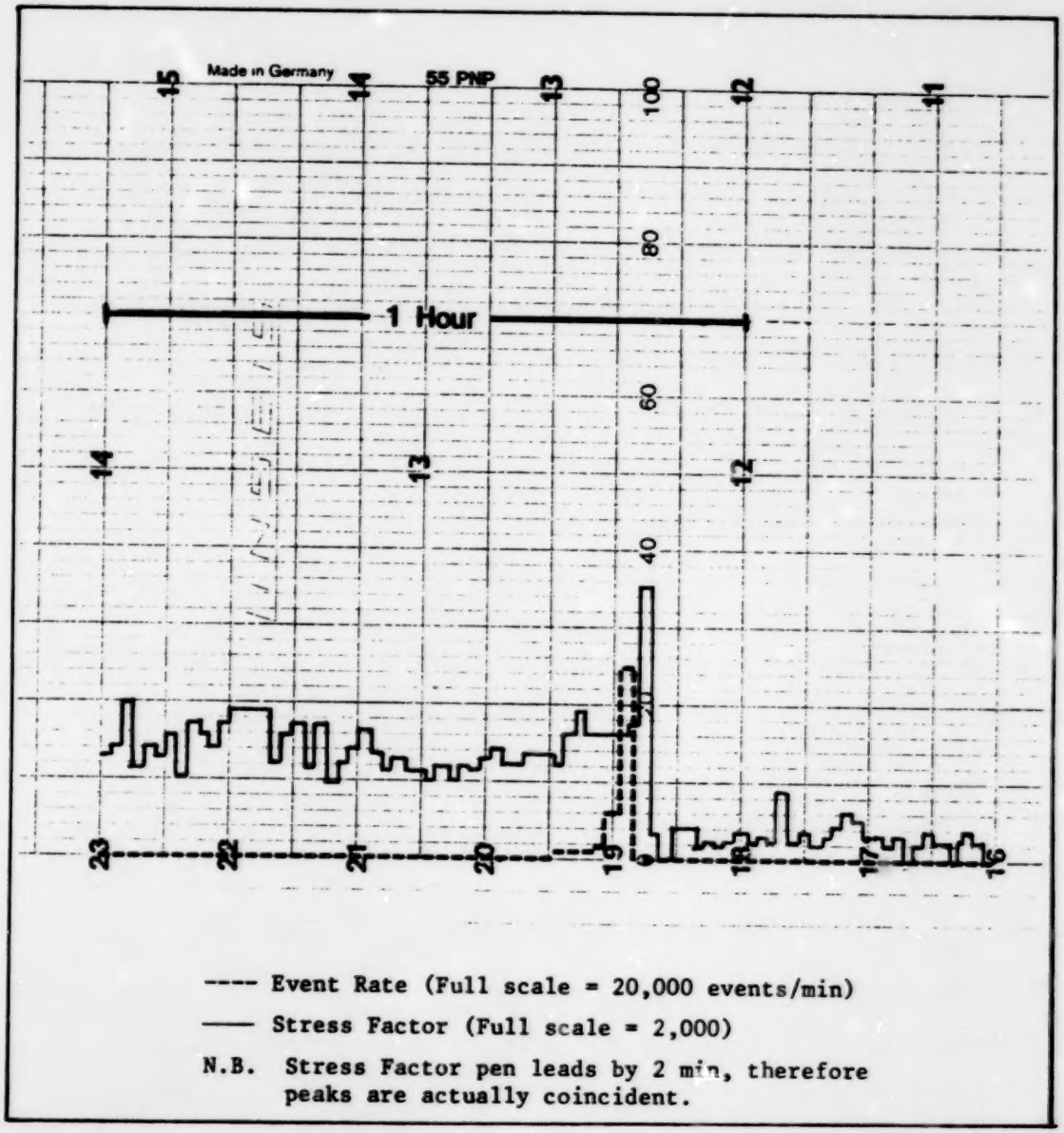

Made in Germany
55 PNP
1 Hour
---- Event Rate (Full scale = 20,000 events/min)
—— Stress Factor (Full scale = 2,000)
N.B. Stress Factor pen leads by 2 min, therefore peaks are actually coincident.

Fig. 2 - Example chart record.

Locomotive haulage and high-speed conveyors transport ore between the six underground crushers and the shafts.

NEW QUIRKE MINE

Two conglomerate reefs are being mined at New Quirke at depths between 300 and 700 m. The ore dips at an average 17° SW and both conventional slusher and mechanized room-and-pillar stopes are used. Ground support is by mechanical bolts, with occasional steel straps, and full column, resin grouted bolts or friction bolts used as required.

Locomotive-hauled trains are the principle method of haulage to the ore passes and main crusher. A conveyor is used to transport ore from the lower levels crusher to the shaft.

MACLEOD MINE

The steeply dipping siderite orebody (55° to 75° S) has been mined from surface down to the deepest current stopes on M-7 level at a depth of 800 m. The majority of production is from large blasthole stopes, with some sub-level stoping developments.

Rock bolts are rarely used, only in problem areas, and the objective of mining is to remove all rock between the hanging- and foot-walls. Some unsupported excavations are up to 500 m on dip. Ore transport is by scooptrams into ore passes, and high-speed conveyor from the crusher to surface.

At Creighton Mine, tests were conducted at depths between 2,000 and 2,300 m, in mechanized cut-and-fill units and in areas with specific stability problems. Testing took place in both conventional and mechanized stopes at New Quirke, at depths of 600 m and 400 m respectively. The existence of a rockburst zone afforded the opportunity to monitor an area with recognizable stress-related features, including pillar spalling and bursting. At MacLeod

Mine, the test sites were adjacent to large blasthole stopes, at depths between 400 m and 600 m.

To fulfil the objectives stated above, the instruments were installed in working stopes and close to major sources of vibrations (e.g., crusher, in-hole drill, drilling jumbo). Following these tests, the Stress Alerts were used to monitor any stress changes associated with blasting, rock removal or excavation instability.

The amplifier gain in the processor unit was usually set at 80 dB and occasionally at 90 dB, the threshold level being adjusted so that the instrument would only trigger when the transducer was installed on rock, the threshold was therefore effectively set just above the system electronic noise. All events were then considered to be a result of vibrations detected by the transducer. Probable electromagnetic interference was encountered at one site, however, as described below.

Full scale settings on the recorder were varied a little, but this was limited by the linearity of the electronics in the processing unit. In the following accounts, use of the term 'no significant activity (or variation)' is attributed to records where levels are below 5% full scale, equivalent to around 1,000 events, or a stress factor of 100. The validity of this assumption could not be established during these tests, since no failures were monitored, and it is possible that some important information may therefore have been disregarded.

RESULTS

CREIGHTON MINE

Preliminary tests were made with the Stress Alert to establish reproducibility of results and sensitivity to mining operations.

The effects of the mounting method and position of the detector were

investigated. Various mounting methods were examined, including clamping to a rockbolt head and using the weight of a wooden beam or piece of rock to provide pressure on the transducer when installed on vertical surfaces. Provided that sufficient force was applied to maintain positive contact between the detector face and the rock, consistent results could be obtained by adjusting the threshold. However, changes in the position of the transducer, achieved by rotating the transducer arm about the rockbolt, or installing two transducers in close proximity, produced varying results in terms of both event rates and stress factors. Distances of less than 10 cm were sufficient to produce this effect.

Two instruments were installed with detectors against a pillar, at distances of 15 m and 40 m from the centre of a development room in which a twin-boom drilling jumbo and an in-hole drill were operating simultaneously, see Fig. 3. Pauses in the operations occurred for drill rod extensions and on the completion of holes. The further instrument recorded no significant activity during the test.

At distances of approximately 13 m and 25 m from the drilling jumbo and the in-hole drill respectively, gradual increases in the event rate and stress factor were noted, followed by rapid decays in the counts. These decreases were coincident with both drills stopping on the jumbo. This occurred twice at the same location, with maximum values of 5,500 events/min and a stress factor of 250 on both occasions. A very small upward adjustment was made to the threshold, and no further peaks in activity were noted. No significant variation was noted in the records in relation to operations of the in-hole drilling machine. Further tests in the vicinity of scoop trams, a roof bolter and a diesel locomotive indicated that these machines were not sources of interference to the Stress Alert.

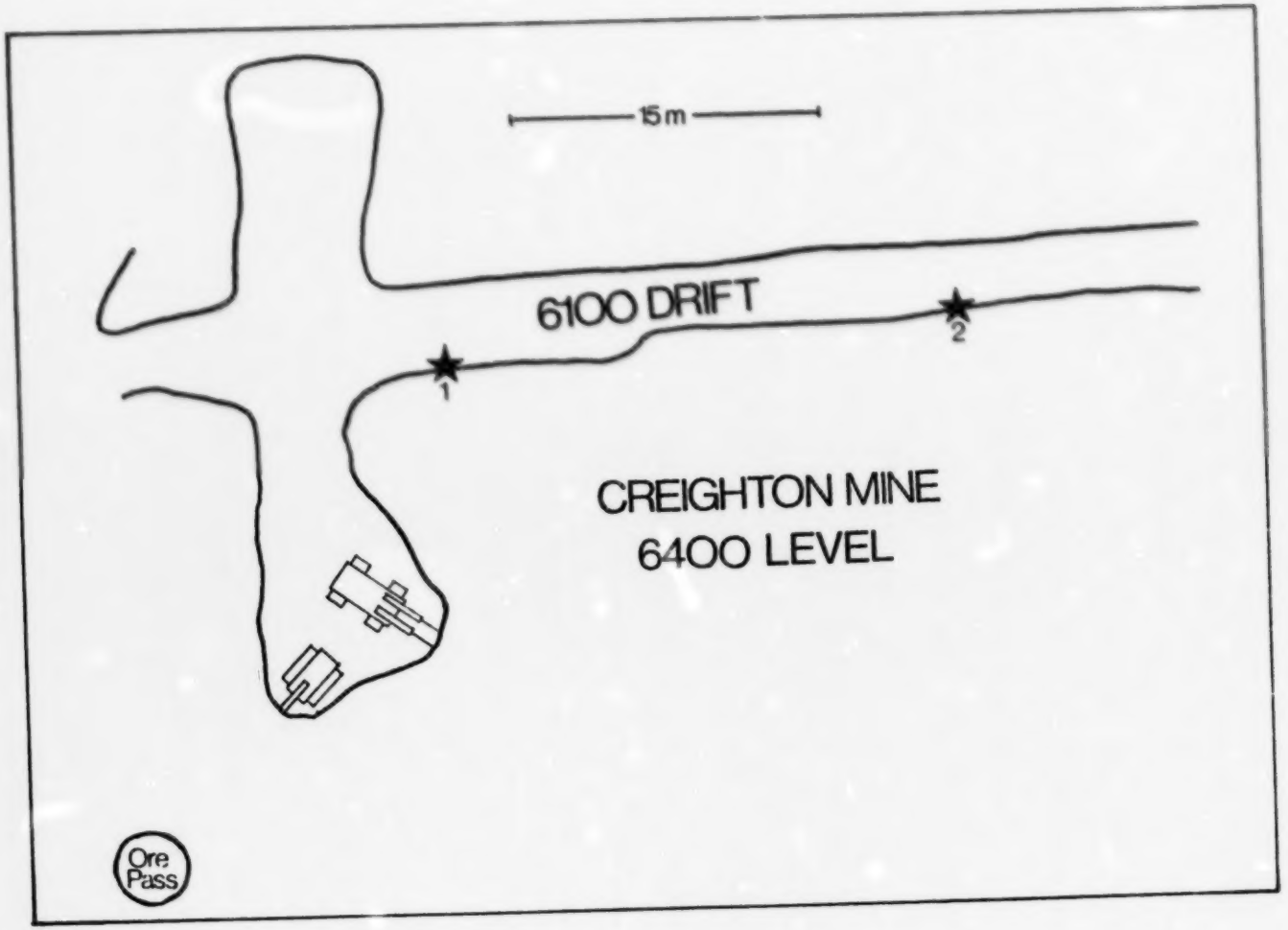


Fig. 3 - Monitoring sites, Creighton Mine, 6400 level.

Blasting was monitored to observe any effects of the explosion itself and the consequent stress redistribution. On four occasions, one instrument was placed close to the blast (10 to 13 m) and one further away (25 to 30 m), both usually on the further side of a pillar in which the blast was being made, see Fig. 4. Invariably, slightly elevated event rates and stress factors were produced at the closer instrument at the time of the blast, and little or nothing was detected at the more distant unit. After one blast the instrument at 10 m from the centre of the blast recorded stress factor readings of approximately 175, five times the pre-blast average, and the largest blast-related peak. This value and the event rate decayed over the following 10 minutes to normal background levels.

Three days were spent monitoring highly-stressed areas, as evidenced by seismic events or rockbursts heard or located by the mine's multichannel monitoring system. Certain computed locations were within 100 m of the Stress Alert site during test periods, however no anomalous records were produced.

One monitoring site was chosen as close as possible to a particularly unstable return air raise, following two rockbursts and intense seismic activity, which continued during the period of study. During two hours of monitoring, many seismic events were heard and several located by the micro-seismic system, around a brow in the raise 40 m from the detector. Material from small bursts was observed falling down the excavation. However, there were no significant variations in activity detected by the Stress Alert, the average values being 15 events/min and a stress factor of 70.

Summary

Vibrations produced by a drilling jumbo were detected at a distance of 15 m, but not 40 m. A slight adjustment of the threshold overcame this

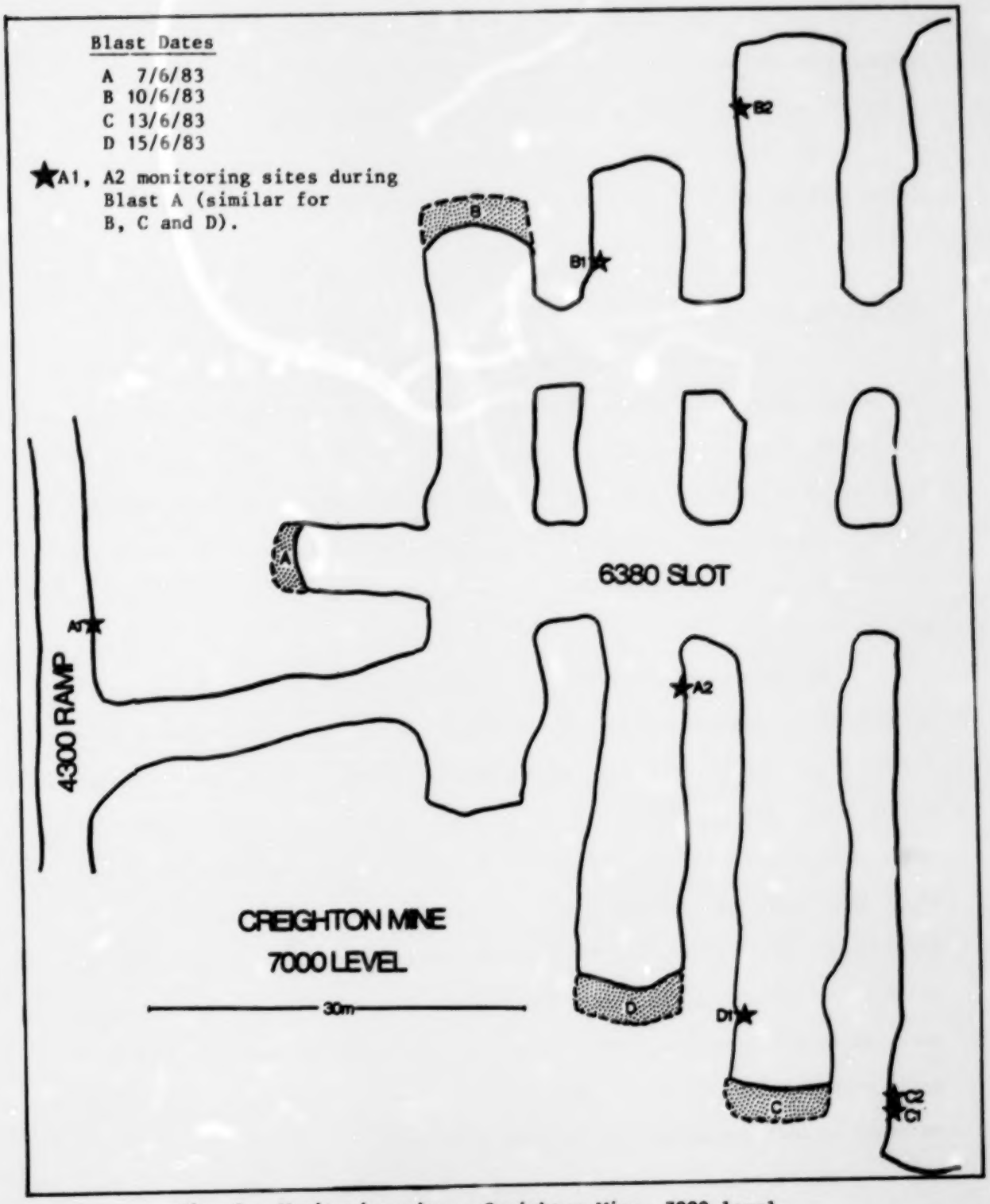


Fig. 4 - Monitoring sites, Creighton Mine, 7000 level.

problem. It was also found that the effects of blasting, both the vibrations produced by the explosion, and some post-blasting events, were detectable at distances up to 13 m, but were not recorded beyond 25 m.

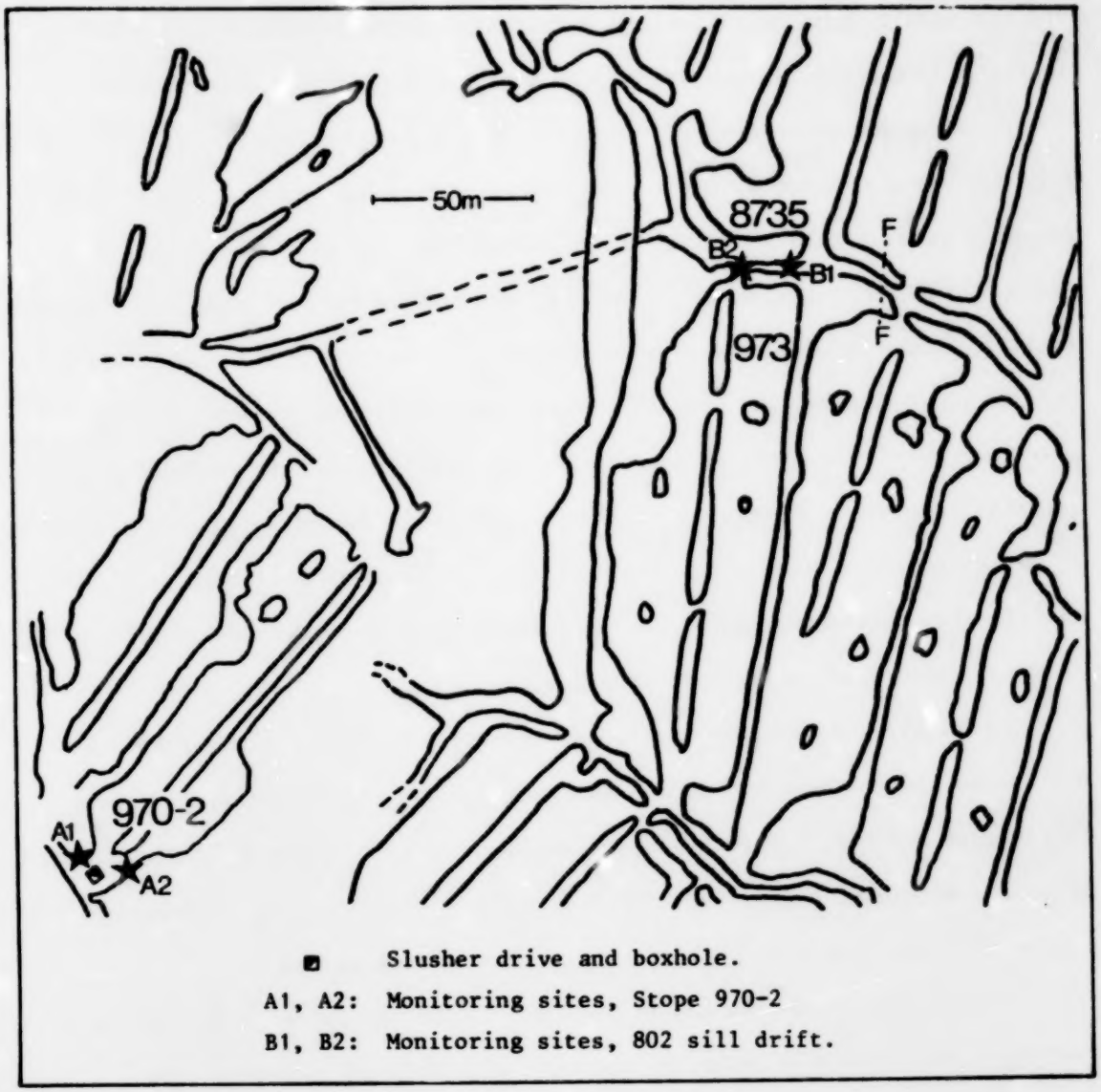
Use of the Stress Alert in highly stressed or unstable ground resulted in no significant activity, despite the fact that seismic events and rock failure occurred within 40 m of the detector.

NEW QUIRKE MINE

The first of the series of tests at New Quirke Mine was to determine the sensitivity of the Stress Alert to vibrations from a crusher. The instrument was installed in the underground station, 5 m from the crusher. The event light appeared to flash with each cycle of the crusher, or at approximately 120 Hz. However, with average rates of 1,000 events/min and a stress factor of 100, no significant variations were recorded during crushing and non-crushing periods.

Two instruments were then installed in active stopes, slusher and mechanized, to confirm any effects of mining operations. Production in slusher stope 970-2 was achieved using two slices through the orebody, the top slice having been completed by the time of the test period. The stope was therefore being benched and a secure site for the Stress Alert was selected behind an electrical panel, approximately 10 m from the slusher drive, see Fig. 5, location A. The detector was then mounted on a roof bolt. Numerous full-scale peaks were recorded in the stress factor, but only six elevated event counts were noted, all less than 1,000 events/min. The activity peaks were particularly pronounced during the slushing shift and only a very small increase was recorded in both parameters at the time of blasting.

The instrument was later relocated away from the electrical panel and slightly further from the slusher drive, using a rockbolt in a pillar to secure



▣ Slusher drive and boxhole.

A1, A2: Monitoring sites, Stope 970-2

B1, B2: Monitoring sites, 802 sill drift.

Fig. 5 - Monitoring sites, New Quirke Mine.

the transducer. Some small fluctuations were then recorded in the event rates and stress factor, never exceeding 20% full scale. Electromagnetic induction in the transducer cable was assumed to be the source of the interference.

The second instrument was installed in a mechanized stope, 4140, in the upper reef. All blasting in the stope had been completed, with a large ore-pile remaining to be mucked out by scooptram. Seismic events had been heard in the area, following the removal of a random pillar. The detector was initially mounted on a rockbolt, beneath a brow, and later relocated, being held in place against the base of a pillar by a large piece of rock. The alarm was heard and reset by an underground supervisor on two occasions, first after a large piece of ore was broken by blasting (sand blasting), approximately 15 m from the instrument. The cause of the second alarm condition is unknown. Additionally, infrequent peaks in the stress factor were recorded, up to values of 600. Event rates were invariably insignificant.

Finally, a site was chosen adjacent to an active rockburst area in New Quirke, where there existed a fault which marked the transition between fairly good and very bad rock conditions, see Fig. 5, location B. Many micro-seismic and seismic events had occurred in the vicinity and small cracking sounds from the roof were heard during the monitoring period.

One week of monitoring in this area, with the detector mounted on a roof bolt 25 m from the fault, on the side with relatively good ground, produced numerous stress factor peaks exceeding 600, and on 22 occasions the results exceeded 1,000, or 50% of full scale output. The event rate records exhibited no significant variations during this period.

For the last two days, the second instrument was installed 15 m from the first detector and further from the fault. Monitoring was therefore conducted at distances of 25 m and 40 m from the perimeter of the severely

affected zone. During the period in which the closer instrument produced 14 stress factor peaks approaching values of 2,000 and frequently exceeded 600, the more distant Stress Alert recorded just one stress factor peak over a value of 600, with other small peaks present. On only two occasions were elevated stress factor levels on the two instruments considered to be coincident. No noticeable failures occurred in the vicinity during the test period.

Summary

While it was observed that vibrations from the crusher were being detected, the consequent number of 'events' was small compared to background levels. A second apparent source of interference is electromagnetic induction due to high a.c. voltage in a stope, was overcome only by relocating the Stress Alert away from the electrical panel. Furthermore sandblasting in the proximity of the instrument proved that it possesses a certain degree of sensitivity to airborne vibrations.

Two instruments were installed in a drift exhibiting rock spalling and failure. The closer unit, at a distance of 25 m from major disturbances, recorded many stress factor peaks, up to full scale on several occasions. A second instrument, at 40 m from the limit of fracturing, recorded few increases in activity and correlation between the two units was poor, as only twice were increased stress factor peaks recorded coincidently. No significant roof-falls or rock failures were observed.

MACLEOD MINE

Three areas of interest were selected for monitoring using the Stress Alert. Two were sites of roof and pillar instability at depths of 500 and 600 m. The third location was close to blasthole stope 3361 where extraction of a total of 40,000 tonnes was planned during the study period, see Fig. 6, locations, A, B and C, respectively.

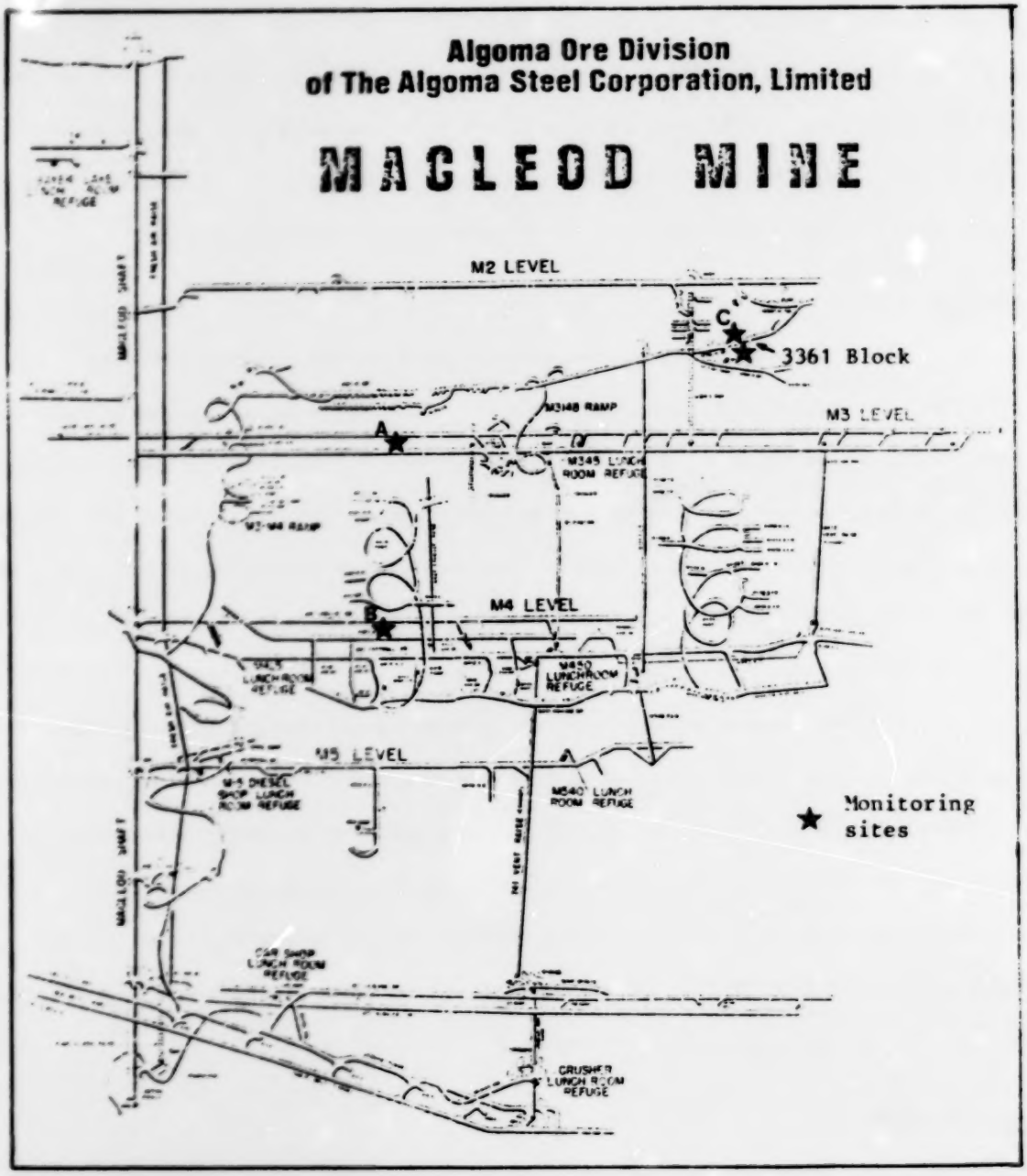


Fig. 6 - Monitoring sites, MacLeod Mine.

Audible microseismic events had occurred in the two areas of instability during the preceding month. After monitoring for a total of 11 days at these two sites, at 30 to 40 m from the points of rock failure, on only one occasion were stress factor and event rates recorded at elevated values. The stress factor remained at full scale, a value of 2,000, for four hours, with an event rate peak at the beginning and end of the period. From this relationship it was concluded that the record was the result of an instrument malfunction rather than an indication of impending rock failure. No further rock deterioration was observed in the immediate area and this pattern of results was not repeated.

The ore block in 3361 stope was 30 m deep at a maximum depth of 500 m, to be excavated using three small blasts to open a large slot, following by a single major blast. Monitoring of the first blast, at location 1 on Fig. 7, involving 4,000 tonnes of ore, produced no peaks in the records, even at the time of firing. It was noted, however, that an open joint existed between the pillar to which the detector was attached, and the block in which the blast took place. The instrument was therefore moved to location 2, between the discontinuity and the ore being blasted. A second 4,000 tonne blast, at a minimum distance of 25 m, again produced no coincident peaks on the Stress Alert records. A subsequent undercut blast, beneath the block under investigation, was succeeded by severe sloughing from the block, when some 2,500 tonnes of ore fractured and fell into the drawpoint before the following shift. Increases in the stress factor and event rate were recorded at about the time of the blast, to values of approximately 100 and 3,000 respectively. However, due to the recorder jamming and stopping before the next visit, the timing could not be precisely correlated.

Commencing eighteen hours after the undercut blast, at least five

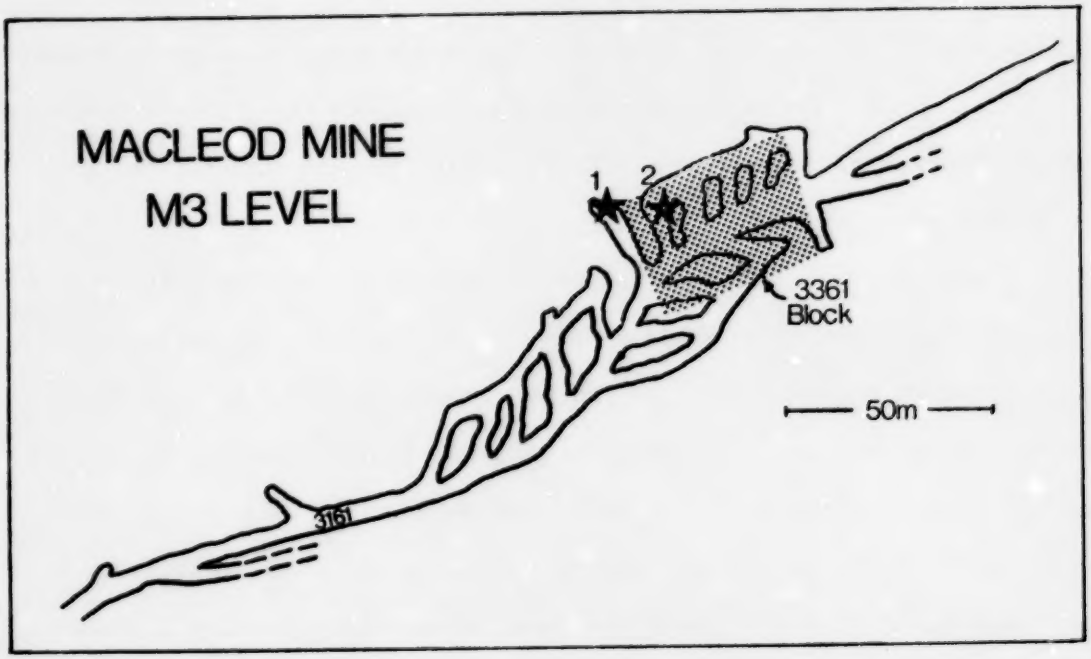


Fig. 7 - Monitoring sites, MacLeod Mine, 3361 Block.

periods, up to one hour long, of abnormal activity were recorded by the Stress Alert. Elevated stress factor values, averaging 100, and event rates up to full scale (20,000 events/min) were visible on the chart.

The major blast, involving 24,000 tonnes of ore, was completed on schedule, but after locating the instrument at the closest safe site, approximately 100 m away, a recorder malfunction caused the loss of the entire record.

Summary

Few conclusive results were produced during two weeks monitoring at MacLeod Mine. Abnormal stress factor or event rate values were anticipated, particularly after adjacent blasts and close to areas exhibiting spalling, but these peaks did not materialize. Conversely, enhanced activity was recorded approximately eighteen hours after major sloughing occurred 75 m away. If these peaks were associated with the spalling problem, then the reason for the intervening eighteen hour 'quiet' period is unknown.

Chart recorder malfunctions were a serious problem, in that timing of events could not be accurately calculated as records terminated when the recorded jammed. This was the case for the minor peaks associated with the undercut blast and subsequent sloughing. It is therefore unclear whether the peaks were caused by the blast vibrations, the stress redistributed by the blast, or were connected with the pillar failure after the blast. Since neither of the first two alternatives were observed for other blasts at Algoma Ore, the last appears most likely, but this cannot be corroborated.

CONCLUSIONS

When installing the Stress Alert, consideration must be given to several factors, including sensitivity to extraneous signals, ability to detect stress redistribution in rock and system security.

It was found that the instrument detected vibrations caused by drilling and blasting when located within 15 m of these sources. Furthermore, apparent electromagnetic interference resulted from installation close to a high voltage electrical panel. Some interference could be eliminated by increasing the threshold level, but the sensitivity was then reduced.

Various methods of mounting the transducer were used, usually with a plastic couplant sheet between detector and rock. Slight adjustments in the position of the sensor were also made at specific locations. Only by adjusting the threshold level could consistent resultsbe achieved.

While the range of sensitivity of the Stress Alert in coal mines has been stated as up to 150 m, results from these tests indicated a lower figure. The apparent range in the hardrock mines visited is 25 m, illustrated by elevated event rates and stress factors at this distance from a zone exhibiting spalling and bursting. At 40 m from the edge of the same area, and at a similar distance from rock bursts in a ventilation raise, no abnormal records were observed.

When attached to the roof in coal mines, the Stress Alert has achieved its primary goal, and provided advance warning of roof falls. In hardrock mines, however, access to the hanging wall is often limited, and since no significant failures occurred during the test periods, it remains to be seen whether the instrument can detect potential failure in hanging wall, pillars and even footwall rocks.

The causes and control of failures in hardrock mines may be investigated using the Stress Alert as a research tool, and as such it would benefit by giving access to the analogue signal and threshold level. Enhancements in these aspects and ensuring that recorder malfunctions do not cause loss of valuable records will result in an improved instrument.

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